

CHAPTER 7

FROST PROTECTION DESIGN FOR AIRFIELD PAVEMENTS

7-1 **SCOPE.** This chapter presents criteria for the design of frost protection for airfield pavements. Included in this chapter are criteria for subsurface exploration as it relates to frost and drainage, and frost protection.

7-2 **RELATED CRITERIA.**

Subject	Source
Pavements	NAVFAC DM-5.04
Soil Mechanics	NAVFAC DM-7.01
Foundations and Earth Structures	NAVFAC DM-7.02
Pavement Design for Airfields	NAVFAC DM-21.10
Airfield Pavement Design	MIL-HDBK-1021 (Series)
Airfield and Heliport Planning and Design	NAVFAC P-971

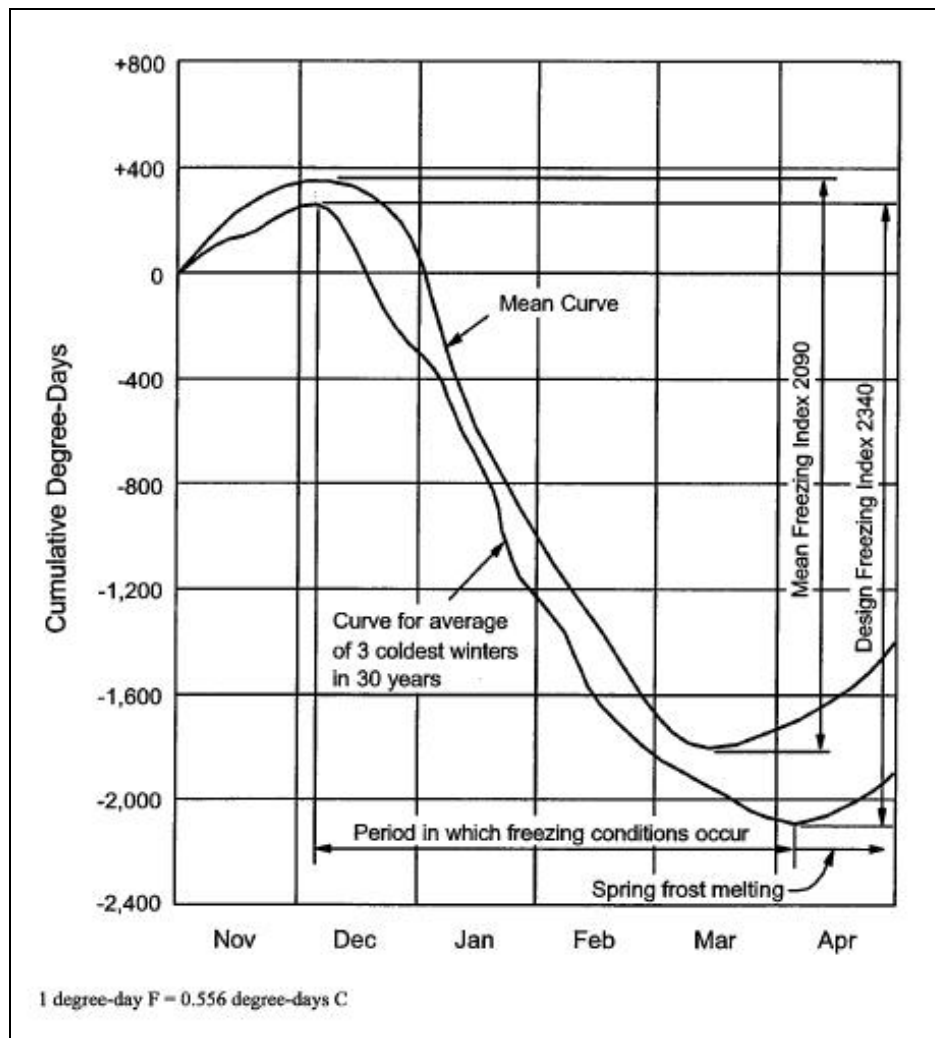
7-3 **DEFINITIONS.** The following specialized terms are used in this chapter.

7-3.1 **Average Daily Temperature.** The average of the maximum and minimum temperatures for one day, or the average of several temperature readings taken at equal time intervals (typically on an hourly basis) during one day.

7-3.2 **Degree Days.** The degree-days for any one day is the difference between the average daily air temperature and 32 degrees F (0 degrees C). The degree days are negative when the average daily temperature is below 32 degrees F (freezing degree-days) and positive when it is above 32 degrees F (thawing degree-days). Figure 7-1 shows curves obtained by plotting cumulative degree-days against time.

7-3.3 **Design Freezing Index.** The average air freezing index of the three coldest winters in the latest 30 years of record. If 30 years of record are not available, the index for the latest 10-yr period may be used. The design freezing index at a site with continuing construction need not be changed more often than once in 5 years unless recent temperature records indicate a significant change in thickness design requirements for frost. Design freezing index is illustrated in Figure 7-1.

7-3.4 **Freezing Index.** The number of degree-days between the highest and lowest points on a cumulative degree-days versus time curve for one freezing season. Freezing Index is a measure of the combined duration and magnitude of below-freezing temperatures occurring during any given freezing season. The index determined for air temperatures at 1.35 m (4.5 ft) above the ground is commonly designated as the air freezing index, while that determined for temperatures immediately below the surface is known as the surface freezing index.

Figure 7-1. Example Determination of Freezing Index

7-3.5 **Frost.** As it related to pavements, frost is the condition of free water freezing within the pavement structure or in the subgrade. The action of frost includes expansion or heaving, as well as the loss of support during the melt period. The frost action may result in the formation of ice crystals in any frost-susceptible material within or below the pavement structure to which freezing temperatures penetrate.

7-3.6 **Mean Daily Temperature.** The average of the average daily temperatures for a given day for several years.

7-3.7 **Mean Freezing Index.** The freezing index determined based on mean temperatures. The period of record over which temperatures are averaged is usually a minimum of 10 years, the preferred being 30 years. The latest available data should be used. Mean freezing index is illustrated in Figure 7-1.

7-4 **EFFECTS OF FROST ACTION.** Frost action can cause differential heaving, cracking, surface roughness, blocked drainage, and a reduction in bearing capacity during thaw periods. The extent of these problems ranges from slight to severe, depending on the type and uniformity of the subgrade soil and availability of water. The most effective method of addressing the effects of frost action is taking measures to avoid this problem. This is typically accomplished by either removing and replacing all frost-susceptible material within frost penetration depth, or providing sufficient cover over the susceptible material with non-frost susceptible material.

7-4.1 **Frost Heaving.** Upon freezing, the volume of water expands by about 9 percent; however, this volume expansion alone is not sufficient to account for the heaving of several inches or more that occurs in some pavements. Frost heaving results from the growth of ice lenses in susceptible subgrade or unbound materials in the pavement structure. Uniform heave is generally not troublesome, but nonuniform heave can result in serious surface irregularities in flexible pavements and cracking in rigid pavements. Differential heave is usually the result of variations in subgrade soils, soil moisture, and transitions from cut to fill with high groundwater level.

7-4.2 **Formation of Ice Lenses.** Ice lenses form in soils that are highly susceptible to capillary action. As the soil is slowly cooled, the water in the voids begins to freeze to form ice crystals. If the soil is susceptible to capillary action, water is drawn to these ice crystals, which grow to form ice lenses. The ice lenses continue to grow as long as the freezing conditions remain and supply of water is present. To have serious formation of ice lenses, three conditions must exist:

- a. Presence of frost-susceptible materials.
- b. Penetration of freezing temperatures into the susceptible material.
- c. Available supply of water.

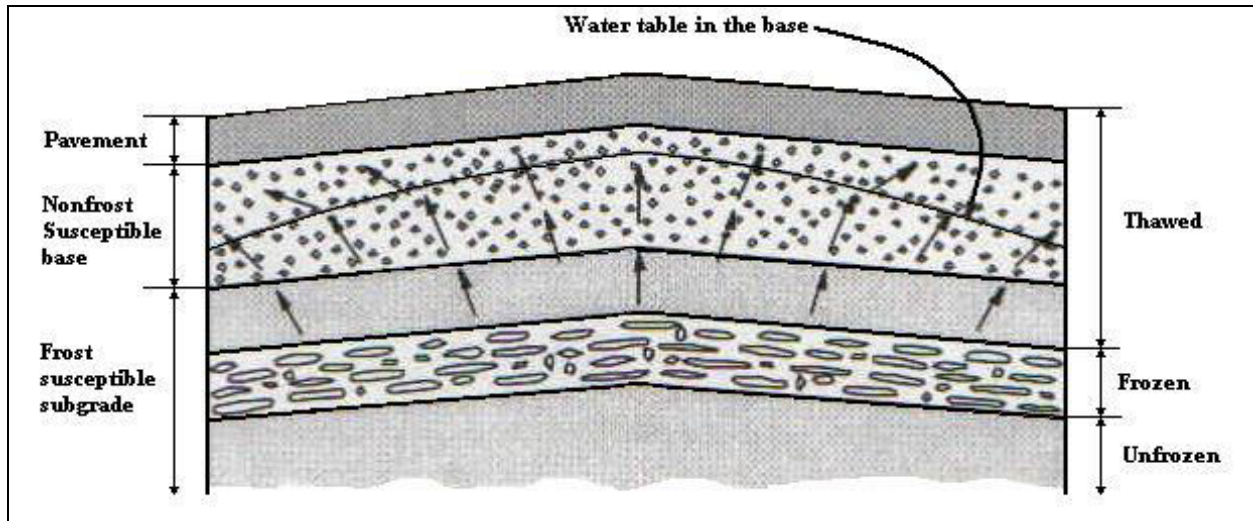
The potential for significant frost heaving is the greatest when the groundwater table is relatively close to the surface and just below the freezing zone. Surface infiltration and lateral flow are other potential sources of water; however, when freezing starts and a layer of ice develops, the water supply from above will be cut off by the ice layer itself.

7-4.3 **Thawing and Reduction in Bearing Capacity.** During thawing periods, the upper ice lenses melt, releasing water into the base course (see Figure 7-2). If the pavement structure is inadequately drained, or if the drains are blocked with ice, the base course becomes saturated and weakened. Traffic during this period causes large pavement deflections and the development of high pore pressures. The resulting problems are the same as those associated with excess free water in the pavement structure discussed in Section 6-1.5.

7-5 **GENERAL PRELIMINARY DESIGN DATA.** The need for frost protection must be identified during the design stage to enable incorporation of appropriate features into the pavement design. Verification of design assumptions is important to

obtain reliable designs. If during construction any of the site conditions were found different than those assumed in the design, the design may have to be modified. Various site-related factors affect the need for frost protection and the need for subsurface drainage.

Figure 7-2. Upward Movement of Moisture into Base Course During Thaw Period



7-6 INVESTIGATION FOR FROST DESIGN. The key factors that determine the need for frost protection include type and gradation of subgrade, climate, and depth of groundwater table. Frost heaving will occur only if the following three conditions exist:

- a. Presence of frost-susceptible material.
- b. Penetration of freezing temperatures into the susceptible material.
- c. Available supply of water.

The investigation for frost design involves evaluating site conditions for the determination of the presence of these conditions.

7-6.1 Subsoil Investigations. Frost action is detrimental if it results in differential heaving, which is caused by variations in subsurface conditions. Variability of subsurface conditions, therefore, is an important consideration for frost design. Subsoil investigation should include assessment of horizontal and vertical variations in subgrade soil type, natural moisture content, and water table elevations. In some situations, variable pavement sections may be needed for different parts of the project to accommodate the differences in subsurface conditions along the project. These conditions must be identified during the subsoil investigation. Consider removing isolated pockets or sections of frost-susceptible soil to eliminate abrupt changes in subgrade conditions.

7-6.2 Classification of Soils for Frost Susceptibility. Frost susceptibility of a soil is the potential for the formation of ice lenses in the soil under freezing conditions. Because the water needed for formation and growth of ice lenses is supplied through capillary action, severe frost heave occurs in soils with a high capillary rate. As the freezing temperatures penetrate deeper into the ground, a heavy formation of ice lenses takes place at each successive level, resulting in severe frost heave. All inorganic soils that contain more than 3 percent by weight of particles finer than 0.02 mm in diameter are generally frost-susceptible. Some uniform sandy soils that contain as much as 10 percent finer than 0.02 mm may remain non-susceptible. These sands are usually interbedded with other soils and, in general, cannot be considered separately. Frost-susceptible soils have been classified into four groups (F1, F2, F3, and F4) according to the degree of susceptibility, as shown in Table 6-2. The following are additional comments on the frost susceptibility of various types of soils:

7-6.2.1 Sands and gravels. Little or no frost action is likely to occur under normal freezing conditions in sands, gravels, crushed rock, cinders, and similar granular materials when they are clean and free draining. The large voids permit water to freeze in place without segregation into ice lenses.

7-6.2.2 Silts. Typical silts, such as rock flour, are highly frost-susceptible because of the combination of relatively small voids, high capillary, and relatively good permeability of these soils.

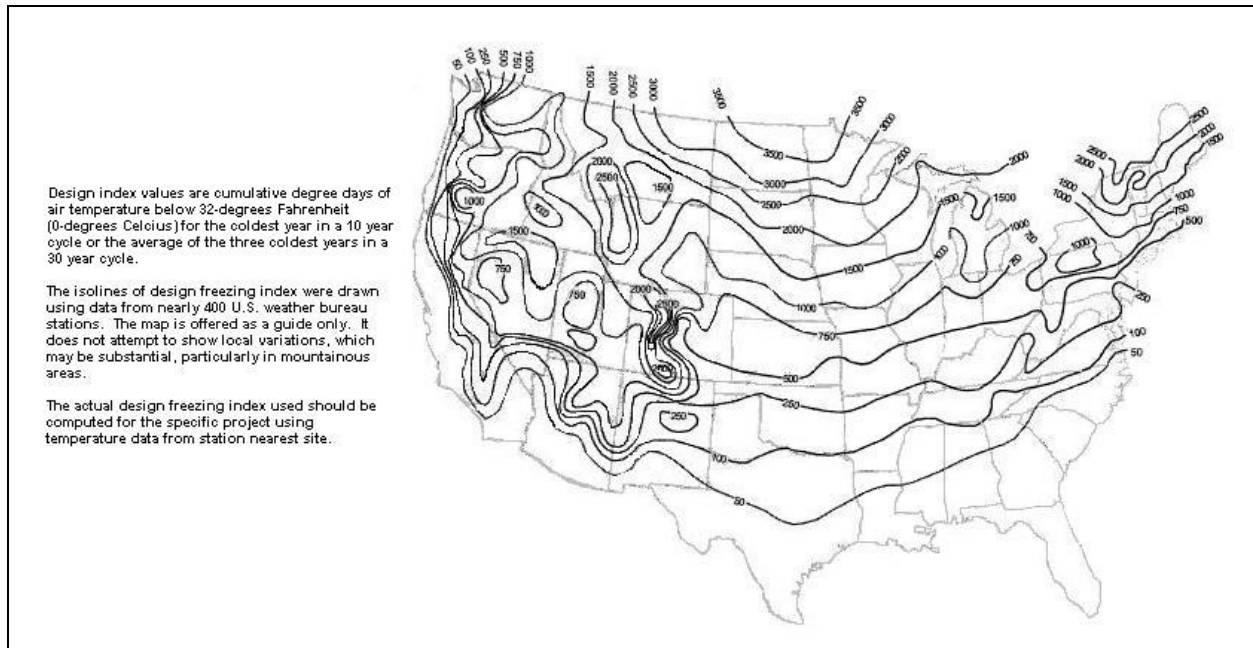
7-6.2.3 Clays. Clays are usually cohesive and have high potential capillary, but their capillary rate is low. Frost heaving may occur in clays, but not as severely as in silts because of the impervious nature of the clays, which makes passage of water slow. Although significant heaving does not occur in clays, clayey soils are not necessarily free of the adverse effects of frost action. Moisture introduced into the soil during thaw periods because of melting ice can cause a drastic reduction in stiffness of clayey soils. Thawing usually takes place from the top down, leaving very high moisture content in the upper strata. Upon saturation, the stiffness of clayey soils can drop by a factor of two or more, compared to that under dry conditions.

7-6.2.4 Varved Clays. Varved clays consist of alternating layers of medium gray inorganic silt and darker silty clay. The thickness of the layers rarely exceeds 0.5 in. (13 mm). Where subgrade conditions are uniform and there is local evidence that the degree of heave is not exceptional, the varved clay may be assigned to Group F3 for frost susceptibility. Nonuniform varved clays are considered to have very high frost susceptibility.

7-6.3 Temperature Design Values. For frost considerations, the design freezing index is the basic value for measuring temperature effects. Freezing index is proportional to the magnitude and duration of subfreezing temperatures during the winter season. For airfield pavement design, the design freezing index is the freezing index for the coldest year in a 10-yr cycle or the average of the three coldest winters in the latest 30 years on record. Figure 7-3 shows design freezing index values for the

continental United States. Values for locations not shown in Figure 7-3 should be determined using the terms from Section 7-3 and the procedure illustrated in Figure 7-1.

Figure 7-3. Distribution of Design Freezing Index Values in the Continental United States



7-6.4 Local Frost Data. Local history of frost heaving may be a strong indication that careful evaluation of site conditions for frost activities is needed. Study all locally available records of maximum and differential frost heaving of airfield and highway pavement in the area. Local public utility companies may be a good source of information for depth of soil freezing.

7-6.5 Water Source for Ice Formation. A groundwater level within 1.5 m (5 ft) of the proposed subgrade elevation is an indication that sufficient water is available for ice lens formation, if the subgrade is frost-susceptible. Other conditions that warrant special attention include the following:

- a. Homogeneous clay subgrade soils contain sufficient moisture for ice formation, even with the depth to ground water in excess of 3.0 m (10 ft).
- b. Unsealed joints and cracks in pavement surface, poorly drained pavements, and shoulder surfaces are common sources of trapped water.

Identification of all potential sources of water for frost activity is an important aspect of site investigations. The pavement design should incorporate appropriate joint details and grades to minimize surface infiltration water.

7-7 FROST PROTECTION DESIGN

7-7.1 Need for Frost Protection. Differential frost heaving can cause pavement cracking, significant roughness, and a drastic reduction in pavement service life. If prevented from free movement, frost heaving can exert enormous forces on pavements, structures, or utilities. The forces involved are so great that any attempt to accommodate frost heaving by providing a more substantial pavement structure is not practical. The only practical solution is prevention. Even if frost action does not result in significant heaving, the excess free water during thaw periods, and consequent softening of the subgrade and base material, can also be detrimental to pavement performance. If the investigation for frost design reveals that frost action is possible at the project site, frost protection design must be considered. In general, the following combination of conditions denotes a potential for frost action and the need for frost protection:

- a. Presence of frost-susceptible soil.
- b. Groundwater level within 1.5 m (5 ft) of the proposed subgrade elevation.
- c. Frost penetration depth greater than the planned overall thickness of the pavement structure (typically, design freezing index greater than 83.3 degrees C [150 degrees F]).

7-7.2 Design Approach. There are two basic approaches to frost protection: (a) complete prevention of subgrade freezing and (b) limiting frost penetration into the subgrade. The first method involves providing a sufficient cover over the frost-susceptible material to prevent penetration of freezing temperatures into the subgrade. This may require removing and replacing a certain thickness of frost-susceptible material or providing a layer of non-susceptible fill, if the combined thickness of the pavement structure and any fills needed for geometric requirements are not sufficient to provide adequate cover. The second approach allows limited frost penetration into the subgrade. The applicability and details of each of these design approaches are discussed in the following.

7-7.3 Design to Prevent Subgrade Freezing. In this method, the adverse effects of frost action are eliminated by preventing the freezing temperatures from reaching the frost-susceptible subgrade. This is accomplished by providing a cover of sufficient thickness of nonfrost-susceptible material over the susceptible subgrade.

7-7.3.1 Criteria for Application. This is the only acceptable method of frost protection in all areas where freezing of the subgrade beneath the pavement structure is possible, if accompanied by any of the following conditions:

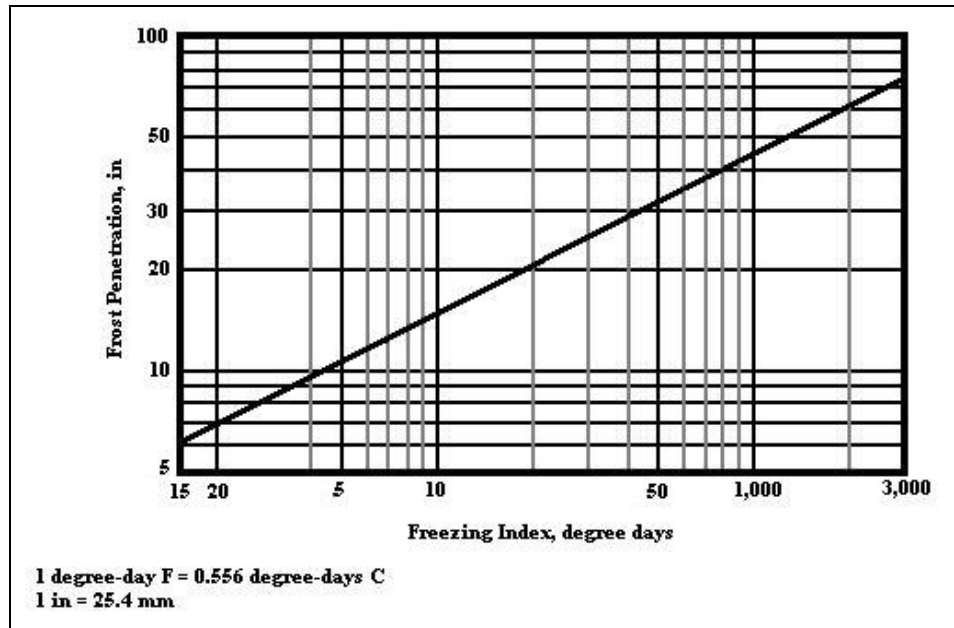
- a. Subgrade soil and moisture conditions are extremely variable.
- b. The subgrade soil belongs to the frost group F3 or F4.

- c. Limited differential heave can present severe operational problems.

7-7.3.2 Design Procedure.

7-7.3.2.1 Determine the design freezing index and depth of frost penetration from Figures 7-3 and 7-4, respectively. Adjust these values based on local experience, if reliable information is available.

Figure 7-4. Empirical Relationship Between Freezing Index and Frost



7-7.3.2.2 The frost penetration depth determined in the step above (7-7.3.2.1) is the required overall pavement thickness, which includes asphalt or concrete surface, base, subbase, and any additional nonfrost-susceptible material courses. The additional depth of material required for frost protection must consist of nonfrost-susceptible material. Refer to MIL-HDBK-1021 Series and NAVFAC P-971 to determine the minimum required base and subbase thicknesses.

7-7.4 Design to Limit Frost Penetration in Subgrade

7-7.4.1 **Criteria for Application.** Use this method for all but the situations described in 7-7.3.1.a above.

7-7.4.2 Design Procedure

7-7.4.2.1 Determine the design freezing index and depth of frost penetration from Figures 7-3 and 7-4, respectively. Adjust these values based on local experience, if reliable information is available.

7-7.4.2.2 From the frost penetration depth determined in 7-7.3.2.1 above, subtract the proposed thickness of asphalt or concrete surface course, and multiply the remaining thickness by $\frac{2}{3}$. This value is the thickness of limited frost penetration into the subgrade. Provide the required base, subbase, and any additional fill to equal the thickness of limited frost penetration into the subgrade. The material in each of these courses must be nonfrost susceptible.